IMPLEMENTATION OF AC-AC CONVERTER FOR INDUCTION HEATING USING LOW COST EMBEDDED CONTROLLER

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Abstract: *A single-switch parallel resonant converter for induction heating is simulated and implemented. The circuit consists of an input LC-filter, a bridge rectifier and a controlled power switch. The switch operates in the soft commutation mode and serves as a high frequency generator. The output power is controlled via switching frequency. A steady state analysis of the converter operation is presented. The experimental results are compared with the simulation results.*

Key words: *Electronics, AC-AC converter, induction heating, soft commutation, Embedded control.*

1. Introduction

Static frequency converters have been extensively applied in industry as a source of medium –frequency power supply for induction heating and melting installations. They are applied in all branches of the military, machine-building industries, for jewellery, smithy heating, domestic heating , cooking devices and other purposes.

The ordinary circuit of an AC-AC converter for induction heating, typically includes a controlled rectifier and a frequency controlled current source or a voltage source inverter. It is a well known fact that the input rectifier does not ensure a sine wave input current, and is characterized by low power [1-3]. Recently many studies of high power factor rectifiers with a single switch have been made [4-5]. These schemes are also characterized by a close to sine wave input current. Three phase AC to DC converters with improved power quality is given by [7]. High frequency voltage fed inverter with phase shift control for induction heating is given in [8-10]. The above literature does not deal with embedded implementation of the AC to AC converter fed induction heater. In the present work, an embedded controlled AC to AC converter is introduced and implemented.

In the scheme (Fig.1) of the AC-AC converter there are two main advantages: It is characterized by a high power factor and a sine wave input current, and On the other hand, the inverter circuit is constructed with a single controlled switch, which serves as a high-frequency generator for induction heating.

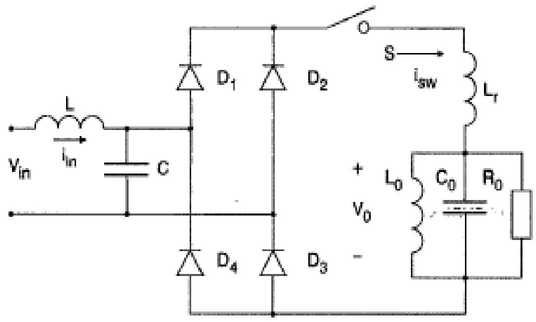
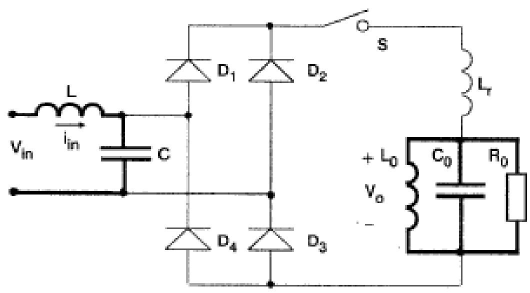


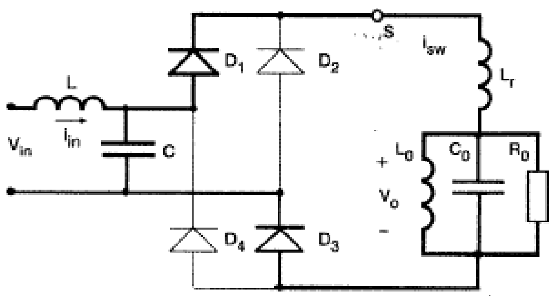
Fig.1. Single switch AC-AC converter

2. Principle of operation

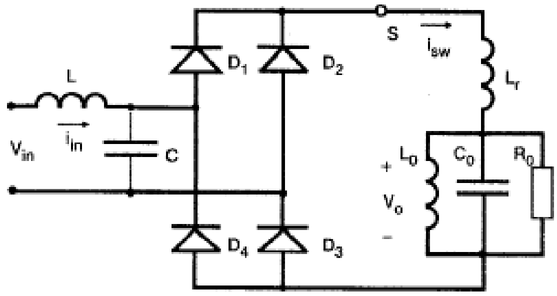
The operating principles of the circuit are illustrated by Fig.2 .



a Mode I (to-t1)



b. Mode II (t1-t2)



c. Mode III (t_2-t_3)

Fig. 2. Equivalent Circuits

The theoretical waveforms are shown in Fig.3.We suppose the switching frequency is much higher than the input line frequency and in the analysis we arbitrarily chose the time interval where vin>0.

2.1 Interval 1: t0<t<t1

The equivalent circuit is shown in Fig.2a. Four diodes D1-D4 and the switch S are off. In this interval the capacitor C charges up practically linearly at a rate and a polarity corresponding to the instantaneous input voltage vin.

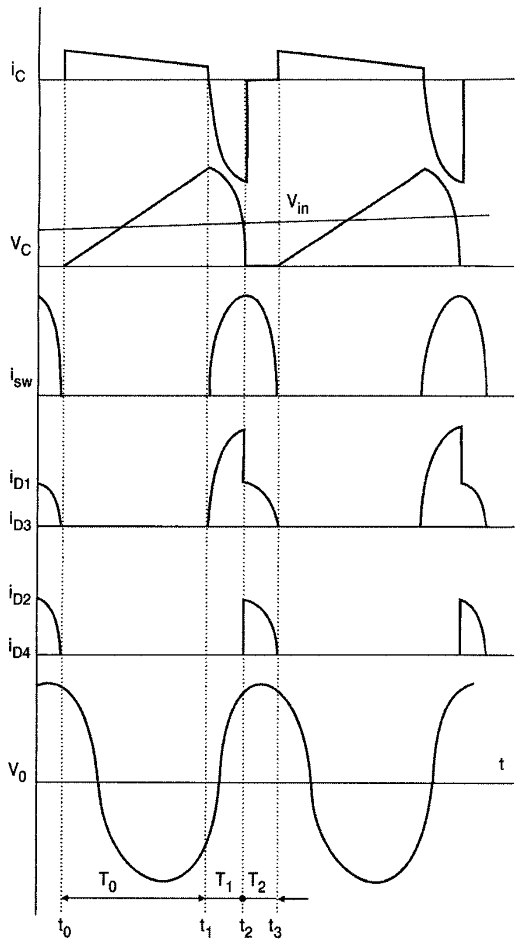


Fig.3. Ideal Switching Waveforms

2.2 Interval 2: t1<t<t2

The equivalent circuit is shown in Fig.2b. Two diodes D1, D3 and the switch S are on. In this interval the capacitor C discharges via the circuit C-D1-S-Lr-load-D3. This interval ends when the capacitor voltage reduces to zero.

2.3 Interval 3: t2<t<t3

The equivalent circuit is shown in Fig.2c. All the diodes and the switch S are on. In this interval the current flows through switch S via two parallel bridge branches. This interval ends when the switch current decreases to zero. At this moment the switch turns off and the process starts from the beginning.

3.Operation analysis

An analysis of the circuit operation is based on the commonly accepted assumption that all circuit components are ideal. The approximate analytical calculations are based on two additional assumptions: the switch current can be approximated by a semi sinusoidal, and the load power is determined by the first harmonic of the load voltage. In this converter optimal range of normalized parameters was chosen. The maximum normalized value of switch voltage is (v*swmax = vswmax / vB = 4 – 5) . To provide these values it is necessary to choose the following ranges of the normalized circuit parameters:

$$L_1^* = \frac{L_r}{L_0} = 0.1-0.2;\ \omega_r^* = \frac{1/\sqrt{L_r C}}{\omega_B} = 3-5;\ \omega_s^* = 1.1-1.9 \quad \text{------ (1)}$$

Evaluation of the relationship between input and output voltages Mg = Vo/Vin

$$A_1 = \frac{I_{sw.\max}}{i_{in}} = \frac{\pi}{D}.\frac{(1-D+D_1)}{1-\cos(\pi\frac{D_1}{D})} \quad \text{----- (2)}$$

$$A_2 = \frac{I_{sw1.\max}}{I_{sw.\max}} = \frac{2D}{\pi(1-4D^4)}.\cos(2\pi D) \quad \text{------ (3)}$$

$$A_3 = \frac{I_{R1.\max}}{I_{sw.1.\max}} = \frac{1}{\sqrt{1+R_0^{*2}(\omega_s^* - 1/\omega_s^*)^2}} \quad \text{------- (4)}$$

$$M_g = \frac{V_{o.r.m.s}}{V_{in.r.m.s}} = \frac{\sqrt{2}}{A_1.A_2.A_3} = \sqrt{2}\frac{\sqrt{1+R_o^{*2}(\omega_s^* - \frac{1}{\omega_s^*})^2(1-\cos(\frac{\pi D_1}{D}))}}{1.1\pi(1-D+D_1)} \quad \text{------- (5)}$$

This relationship is expressed in Fig. 3.a.

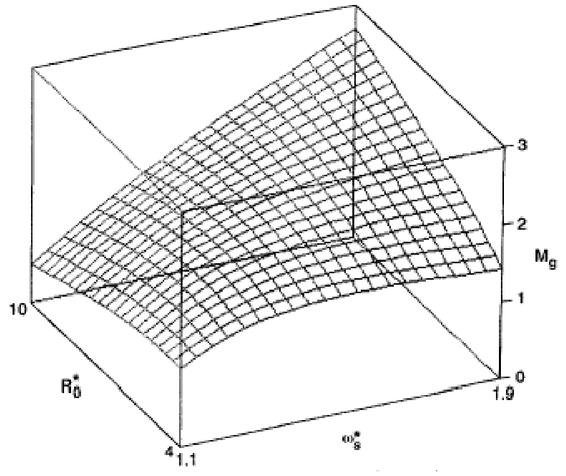


Fig. 3.a. Factor Mg against parameters Ro* & ωs*

The values of duty cycles D1 and D may be calculated from the plot Fig.3.b.

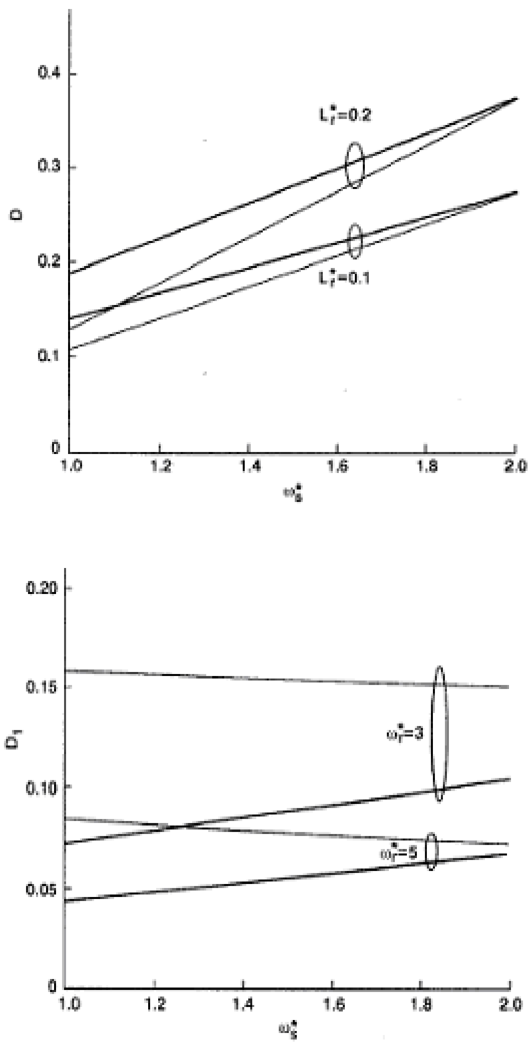


Fig.3.b. Duty cycle against parameters Lr*, ωs*

The values of duty cycles D1 and D may also be found from the approximate polynomial expressions

$$D_1 \approx (325.8 - 36.7\omega_r^* - 33.4\omega_s^* - 25.4R_0^* + 2.2\omega_r^* R_0^* + 7.4R_o^*\omega_s^*)10^{-3}$$

$$D \approx (-88.3 - 445.5L_r^* - 15.5\omega_s^* + 175.1\omega_s^* + 19.3R_0^* + 725L_r^*\omega_s^* - 10.3R_0^*\omega_s^*)10^{-3} \quad \text{----------- (6)}$$

4. Simulation Results

The AC to AC converter fed induction heater is simulated using the matlab simulink and the results are presented here. The circuit model of the AC-AC converter is shown in Fig.4a.. Scopes are connected to measure output voltage, driving pulses and capacitor voltage.

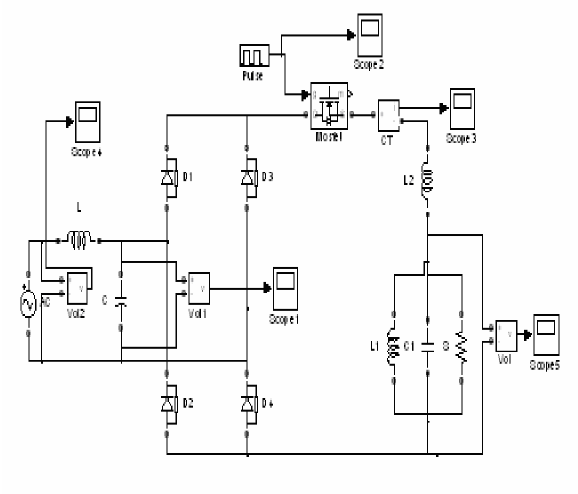


Fig.4a. simulation Circuit

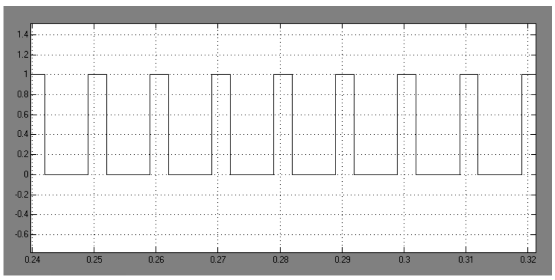


Fig.4b. Driving pulses

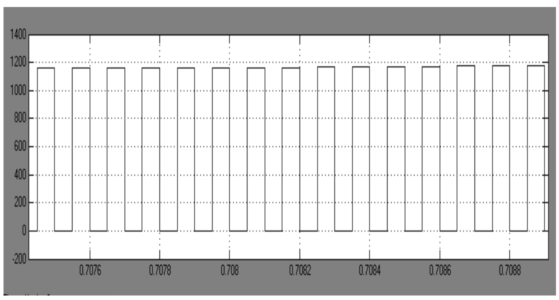


Fig.4c. Voltage across Switch ‘S’ (V_{ds})

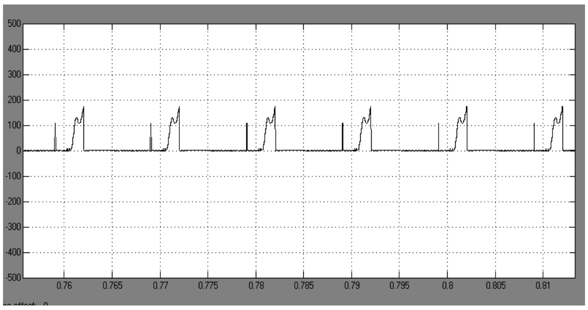


Fig.4d. Current through Switch ‘S’

Switching pulses are shown in Fig 4b.Voltage and current waveforms of the switch are shown in Fig.4c & Fig 4d respectively. Output of converter is shown in fig. 4.e.

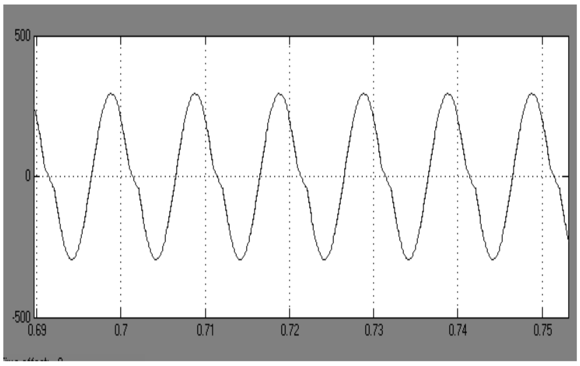


Fig. 4e. Output voltage

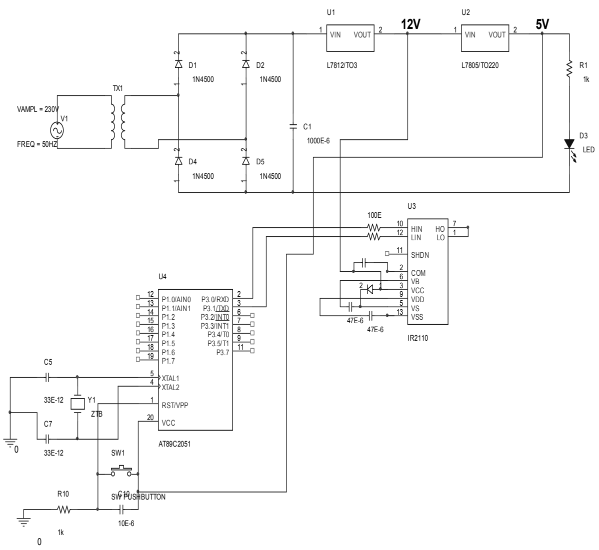


Fig 4.g 89C2051 based control circuit

The ATMEL 89C2051 based control circuit is shown in Fig. 4.g. Atmel microcontroller 89C2051 was used to generate driving pulses for the MOSFET switches. They are amplified using the driver IC IR2110. The gate signal is connected to port pin P1.0. Various steps involved in the firing pulse generation is shown in Fig.4.h. In the flow chart delay1 is reflecting the turn on interval of switch during which pulse will be logic 1, whereas delay2 reflecting the turn off interval of switch during which pulse will be logic 0.

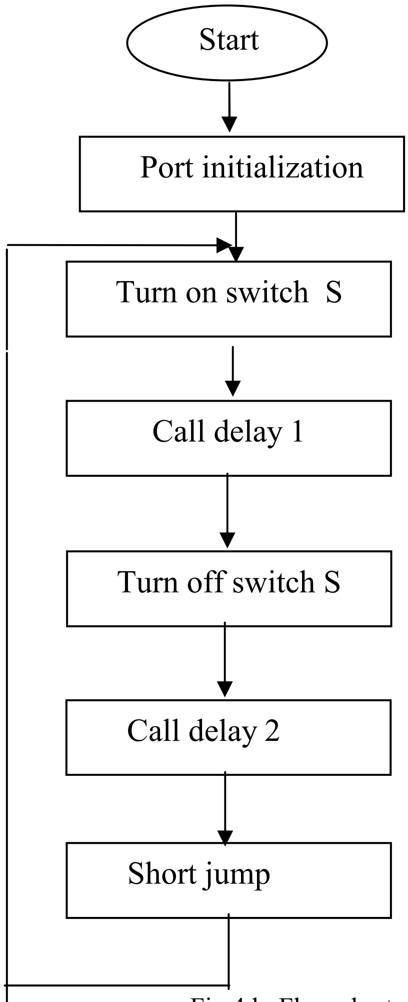


Fig.4.h Flow chart

The comparison on the performance of conventional AC-AC converter and single switch AC-AC converter is presented in Table1. The results confirm that the single switch converter delivers the better performance than any other converter in achieving the better efficiency.

Table I Performance comparison

Input voltage in volts	Output voltage in volts		Efficency in %	
	Convent- -ional converter	Single switch converter	Conve- -ntional converter	Single switch converter
180	129.6	152.4	71.6	84.4
200	144.1	169.4	72	84.7
220	158.2	186.4	72	84.7
240	173	203.5	72.1	84.8

When the proposed converter and the previously developed one are operating under the condition of maximum output power , the power loss analysis is shown in table-II. The power loss dissipation of the newly developed converter is comparatively lower than the previously developed one.

Table II Power losses analysis in the circuit components

Devices and components	Power dissipation	
	Newly developed	Previously developed
Switch	49W	69W
Filter inductor	18W	25W
IH load	58W	58W
Bridge rectifier	23W	27W

5. Experimental Verification

The single-switch AC-AC converter was built and tested at 230V. The experimental setup of the AC to AC converter is shown in Fig.5. The circuit parameters are R0=60Ω; L0=150μH; C0=2.35μF; Lr=22μH; Li=8.0mH; Cin=0.94μF and the switching frequency ωS= (62-113) x103 s-1.The experimental waveform of the output voltage is shown in Fig.6. The input voltage and current are shown in Fig.7. It implies power factor is close to unity. The output power control was also checked and its dependency on the switching frequency is shown in Fig.8. The output power increases with an increase in the switching frequency.

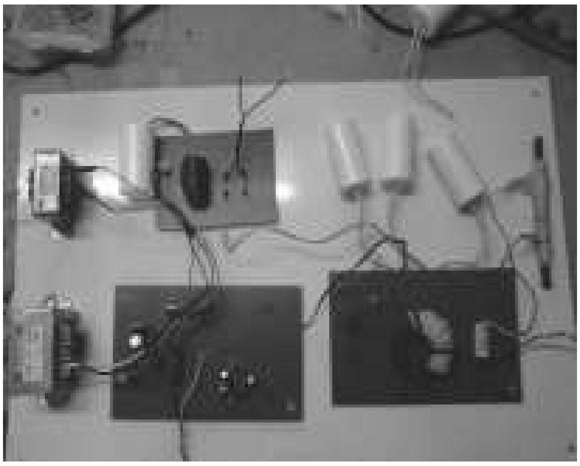


Fig. 5. Hardware layout

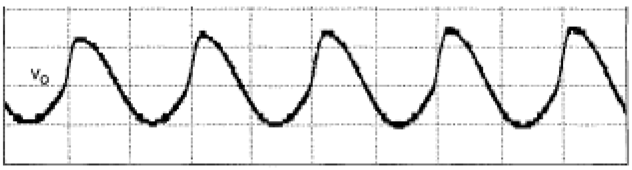


Fig.6 Oscillogram of output voltage

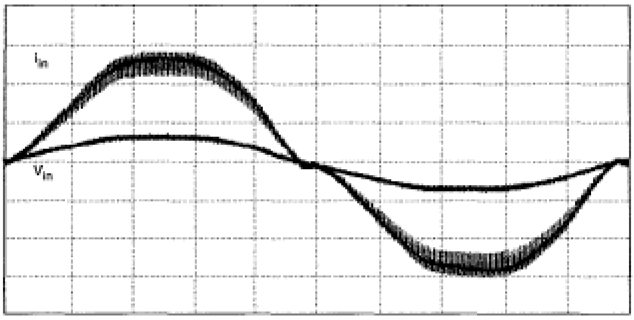


Fig 7. Experimental Input voltage and current

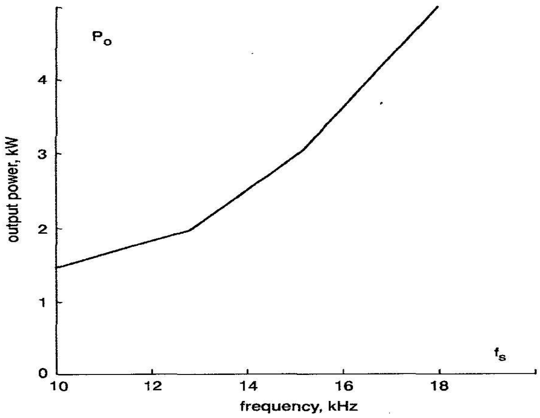


Fig.8. Output power v/s switching frequency

6. Conclusion

An embedded controlled AC-AC converter circuit for induction heating has been simulated and tested. The converter input current is practically sinusoidal and its power factor is close to unity. The circuit topology is very simple since it includes only one power switch. This switch operates in a soft commutation mode. The converter provides a wide-range power control. This converter has advantages like reduced hardware, reduced stresses and high power density. The simulation and experimental results demonstrate the actual converter capability to control the heat. The experimental results agree closely with the simulation results.

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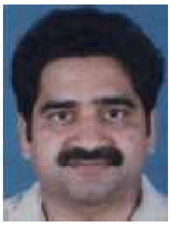

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